

IMPLEMENTING CMMI: SYSTEMS ENGINEERING AND SOFTWARE PROCESS IMPROVEMENT AT NASA'S GODDARD SPACE FLIGHT CENTER

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Abstract Within the complex systems developed throughout the aerospace industry, systems engineering and software are playing an increasingly important role in mission success. NASA is beginning comprehensive agency-wide initiatives to improve software and systems engineering processes and practices to effectively deliver its scientific and technological objectives. Each NASA Center is developing a software process improvement program that will demonstrate measurable improvement through comparison against the Capability Maturity Model (CMM)* or the Capability Maturity Model Integrated (CMMI). At Goddard Space Flight Center (GSFC), we have chosen to implement CMMI and to integrate the systems engineering process improvement program with the ongoing software program. At GSFC, software is a pervasive part of the overall mission system. Software flies on satellites, stays on the ground, runs instruments, manages databases and data, and supports scientific research. Some software is mission and/or safety critical. Coordinating these different types of software in an integrated fashion with the systems engineering, involving organizations with different objectives, is a mammoth task. This presentation will discuss our approach to implementing CMMI. Space might be considered the last frontier but in order to get there we must effectively integrate software and systems engineering for mission success.

* CMMI is a service mark of Carnegie Mellon University. CMM, Capability Maturity Model and Capability Maturity Modeling are registered in the US Patent and Trademark Office

Introduction Software engineering is a core capability and key enabling technology necessary for the support of NASA's missions. Ensuring the quality, safety and reliability of software is of paramount importance in achieving mission success. The exponential growth in the scope, complexity, and importance

of software is expected to continue, challenging our ability to manage it effectively. As a result, the NASA Software Initiative was conceived and the NASA Software Initiative Implementation Plan was developed. NASA's plan is a comprehensive approach for improving software engineering to a quantifiable maturity level commensurate with mission criticality in order to meet the software challenges of NASA. The GSFC implementation of CMMI is a direct result of the NASA plan; therefore, we will start this paper with a brief discussion of the NASA plan and of CMMI before proceeding to the GSFC implementation of CMMI. A committee formed by representatives from all NASA Centers developed NASA Software Initiative Implementation Plan. This Software Working Group (SWG) was designed to be comprehensive and cover all aspects of software development, not just process improvement. It contains four strategies felt to address the necessary areas. The GSFC software process improvement plan focuses primarily on the first strategy listed below, but at a later point in time, the other strategies will also be addressed by GSFC. The NASA strategies for process improvement are:

- Develop and implement Agency-wide and Center plans for continuous software process and product improvement in NASA and Contractor developed software; also establish an infrastructure and measurement system to support improvement.
- Improve safety, reliability, and quality of software products through the integration of sound software engineering principles and standards.
- Provide input for research based on identified software problem areas and infuse research results.
- Improve software engineering knowledge base in NASA, and implement strategies for attracting and retaining software engineers.

More recently another NASA-wide working group was formed to establish processes and best practices for systems engineering on programs

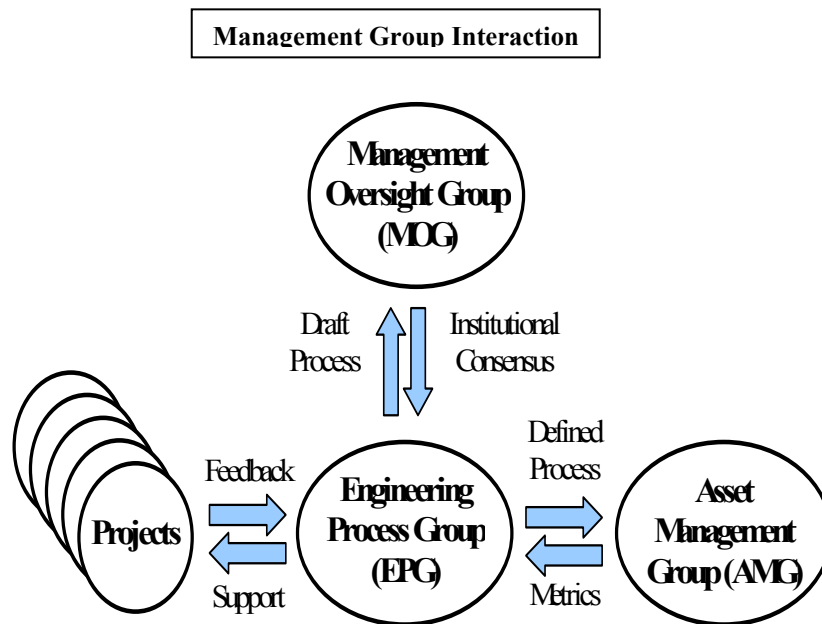
and projects throughout the agency, the Systems Working Group (SEWG). Once these processes and practices are established, the next logical step is to investigate methods for improving the systems engineering processes across the agency and move everyone toward the goals established by the committee. Since the software working group had already begun implementing the CMMI for software, and since CMMI integrates systems engineering and software engineering, the systems engineering working group decided to leverage off of the effort of the software folks and see what could be expected from CMMI when it is applied to both systems engineering and software. They chose to use the effort at GSFC as a pilot program for systems engineering process improvement to find out what “return on investment” can be expected from applying the CMMI model.

1.0 The CMMI Model The Capability Maturity Model Integrated (CMMI) is a guide for process management and quality improvement concepts applied to both systems and software. The CMMI model is designed to help organizations improve their product and service development, acquisition, and maintenance processes. Concepts covered by this model include systems engineering, software engineering, supplier sourcing, and integrated product and process development as well as traditional CMM concepts such as process management and project management. Systems engineering covers the development of total systems, which may or may not include software. Systems engineering focuses on transforming customer needs, expectations, and constraints into product solutions and supporting these product solutions throughout the life of the product. Software engineering covers the development of software systems. Software engineers focus on applying systematic, disciplined, and quantifiable approaches to the development, operation and maintenance of software.

2.0 The Maturity Levels CMMI identifies five levels of maturity (ML1 – ML5) through which an organization evolves as it improves its processes. At the Initial maturity level (ML1), processes are generally undocumented, unpredictable, poorly controlled, and reactive. At the Managed maturity level (ML2), project processes are managed and project plans and process descriptions are documented and followed; implementation schedules and associated costs are detailed. At the Defined maturity level (ML3), the focus shifts to gaining control of your processes as an organization. The organization establishes common processes that are then tailored by the projects, common measurements and common training. Initially, during GSFC’s implementation, the process areas associated with the Defined maturity level (ML3) will be reviewed in detail to ensure that the infrastructure established for the Managed maturity level will support a natural evolution to the Defined maturity level. For GSFC, the initial plan was to achieve Level 3 maturity on all projects determined to be mission critical or otherwise critical to GSFC’s business goals. The systems engineering and software acquisition sections of the CMMI will be implemented as appropriate, but the initial emphasis will be on software development. Historical data shows that it takes an average of twenty-six months to evolve to the Managed maturity level in the Software Capability Maturity Model (SW-CMM). An additional twenty-five months is then needed to evolve to the SW-CMM Defined maturity level. While the CMMI processes are somewhat different from the SW-CMM processes, it is anticipated that the evolution periods will be similar in length, taking about four years to achieve the Defined maturity level. CMMI implementation on each project will begin with the project’s next release, phase, or build and will not be retrofitted.

3.0 Infrastructure for Improvement In order to manage the process improvement effort three organizations were established: the Management Oversight Group, the Engineering Process Group, and the Asset Management Group. These groups will support the implementation of the process area activities and other

improvements identified during the entire process improvement effort. These groups were formed during the initial phase of the implementation. The Groups and their interaction are described below:



3.1 The Management Oversight Group

The Management Oversight Group (MOG) is responsible for ensuring that the process improvement activities are responsive to institutional needs, that an institutional process is defined, and that the stakeholder organizations are committed to using the established policies and procedures. During the initial phases, the MOG continually evaluates the progress and determines the potential source of needed resources. As CMMI implementation is rolled out to GSFC projects, the MOG will determine the schedule for projects and programs participating in the process improvement effort.

3.2 The Engineering Process Group

The Engineering Process Group (EPG) was initially the focal point for software process improvement across GSFC, but it has recently been expanded to include systems engineering. The EPG maintains the overall view of current efforts and facilitates those efforts on a continuing basis. The EPG develops and maintains expertise in process definition, organizational change, and technology related to improving and ensuring software/systems quality. The EPG also facilitates deployment of

improved software/systems development activities by working closely with the projects to

enhance their understanding and application of any new process and technology improvements. This will be critical to the success of the process improvement implementation. EPG members foster collaboration among everyone at GSFC involved with software/systems development process improvement or application of the practice.

The EPG is staffed by software/systems process engineering experts and by software/systems engineers with practitioner experience representing all directorates across GSFC. Members who represent the practitioner community will be rotated approximately every eighteen months in order to maintain the experience base for the EPG.

3.3 The Asset Management Group

The Asset Management Group (AMG) supports the EPG and focuses on the establishment and maintenance of the infrastructure elements necessary to support a continuous process improvement effort. It is chartered with maintaining a profile of GSFC software processes and products, and with the collection of information that will maximize the return on GSFC investment in software intellectual property. These activities will continue throughout the process improvement activities. To this end the AMG is responsible for software

knowledge management, the on-line deployment of GSFC documented software policies and procedures, and the provision of software engineering tools that support GSFC software engineering practices. Although focused on the software process improvement effort, there are plans to expand the AMG to include systems engineering next year.

4.0 Implementation Strategy

The software development process improvement effort at GSFC is divided into three phases:

- Phase 1: Pilot project phase to assess the implementation approach of the process improvement effort and to determine the cost and effort involved with the implementation
- Phase 2: Staged implementation of process improvement effort on all mission critical projects with a goal of improving weaknesses identified by measuring against the process areas in the CMMI Managed maturity level (ML2) and the CMMI Defined maturity level (ML3).
- Phase 3: Sustainment and continual improvement of the process improvement gains in the previous phases.

4.1 Phase 1 Strategy

The implementation strategy used during Phase 1 was to choose several “pilot” areas of GSFC, which are representative of the different types of software and the development processes used. Then, with the assistance of some SEI-certified appraisers, a quick-look mini-appraisal against the CMMI model was done on several projects from each “pilot” area. The results of this mini-appraisal were used to identify needed improvement areas in each project and in the representative “pilot” group as a whole.

Following the mini-appraisal, a team of process engineers from the EPG worked with the projects and their managers to determine the most appropriate method of addressing the identified weaknesses or gaps. As appropriate, the EPG forms action teams to assist the projects in addressing each of the weak process areas. Based on best practices and existing process documentation, these action teams assist the projects in augmenting existing project documentation and will periodically hold workshops or mentoring sessions to strengthen project knowledge in applying the improved processes.

During Phase 1 the focus of the activities was on this baselining process, using the mini-appraisals in order to get a baseline for making a better estimate of the cost and effort involved with the improvement effort. The identification of the needed improvements in the “pilot” areas provided information for developing a work breakdown structure for improvement activities tailored to GSFC’s needs. Phase 1 also concentrated on establishing the improvement infrastructure and training the improvement teams.

4.2 Phase 2 Strategy

At the end of Phase 1, (scheduled to last a year), the EPG will perform an evaluation of the approach used for implementing the process improvement on the pilot areas to determine any necessary changes. Any necessary changes will be recommended to the MOG and the Software Development Process Improvement Plan will be updated accordingly. This information will be supplied to the Systems Engineering Working Group to assist them in determining if CMMI should be adopted for an agency-wide systems engineering process improvement activity.

A schedule will be developed for including GSFC projects in the process improvement effort at a staggered rate based on project schedules and life cycle phases. As projects are scheduled, they will be internally appraised, using the knowledge gained in Phase 1. The EPG will work with the projects to tailor their specific project documentation, and practices using the documentation developed in Phase 1. Metrics will be collected on all projects so process improvement benefits can be determined. Periodic appraisals with SEI-certified appraisers will be scheduled to measure process improvement progress and to determine readiness for a rated appraisal.

As GSFC moves towards the Defined level of CMMI, the process used in Phase 1 of identifying best practices and coupling them with existing project processes to form improved processes will be continued to obtain a set of processes for functional areas. Action teams will also address additional gaps or weaknesses identified during Phase 2.

4.3 Phase 3 Strategy

During Phase 3, which is a continuing phase, the infrastructure of the process improvement effort remains in place, including the three

implementation teams (MOG, EPG, AMG), although the level of effort decreases. The primary activities will be to continue supporting the development, improvement, and application of improved practices. Periodic updates will be necessary to incorporate new best practices and new technology changes. Periodic internal assessments will be performed to assure that the projects are continuing to follow the documented practices. The three teams should continue to operate as a resource to assist projects in the areas of processes, tools, historic information, etc.

5.0 Phase 1 Activities

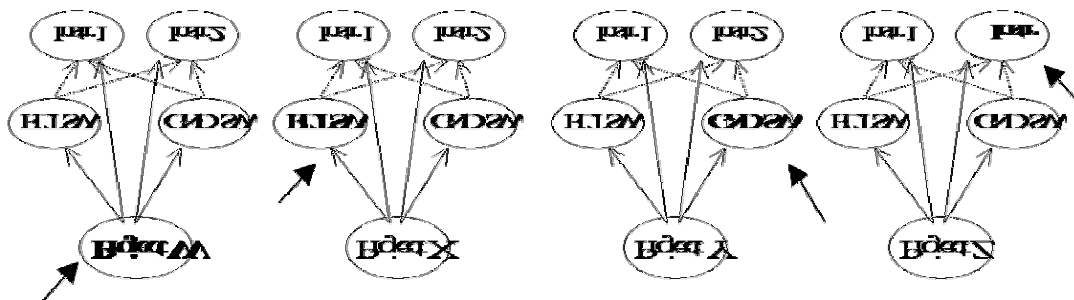
Currently GSFC is working to complete its Phase 1 activities and to begin more detailed planning for Phase 2. As mentioned previously, several pilot areas were chosen to be representative of software developed at GSFC. Then these pilot areas were evaluated against the staged CMMI model using SEI-certified appraisers during mini-appraisals.

The objectives of using pilot projects in Phase 1 of the implementation are to:

- Understand the resources (i.e., resources defined primarily as personnel time) needed to implement process areas in the CMMI Managed maturity level,
- Understand the comprehensiveness and interaction between the process areas,
- Be aware of critical issues and potential problems with process improvement in relation to the GSFC culture,
- Be aware of major issues and the impact of metrics collection required for CMMI,
- Establish the baseline of current costs and quality of software/systems developed.

Originally, four pilot areas were planned. To date, two pilot areas have been appraised and a third is planned for later this year. The appraisal of the fourth area has been deferred due to the unavailability of currently active projects in this area.

5.1 Selection of Pilot Areas At GSFC, a software project can be described in its simplest form as composed of flight software, ground software, and instruments. The flight and ground software along with the instruments will be viewed as suppliers to the project to simplify the application of the CMMI model. Therefore, there are four types of components that need to be assessed against CMMI: the project itself (including systems engineering and acquisition), the flight software, the ground software, and each instrument. It was recommended that there be four pilot areas, one from each component area. For Phase 1, one component project from each pilot area was chosen for improvement activities following the appraisal. This is shown below by the arrows.



Pilot Project Implementation Selection

The following criteria were used to select projects in each pilot area:

- Project is already established so that there are existing procedures to evaluate.
- Project management is stable, willing to support participation in the process improvement effort, and has the necessary funding available.
- Project is comprised of enough project members to ensure that all process areas can be evaluated and improved.
- Project has visibility within GSFC to ensure appropriate emphasis on the process improvement effort.

5.2 The First Appraisal (Software Focus) Our initial appraisal was performed on the Flight Software area, using one completed project with all documentation in place and one project nearing the preliminary design review point. For this appraisal, the organization was considered the flight software organization, and few interviews included people outside of this organization.

Project participants were given a three-day CMMI class, but had very little other preparation for the mini-appraisal. No attempt was made to map their documentation to CMMI process areas or to identify alternative practices that might be in place before the appraisal. Most of the flight software participants were on very tight schedules and every attempt was made to minimize their preparation and interview time during the appraisal process.

A team of six appraisers was used; three were EPG members and three were SEI-certified appraisers from outside GSFC. The appraisal team divided the process areas and each took the lead on interview questions in their area. The appraisal took four days with the majority of the interviews on two days and the remaining two days devoted to document review. Although less formal, a SCAMPI-type (Standard CMMI Appraisal Method for Process Improvement) of approach was used, where findings are the result of team consensus, supported by multiple data points from multiple sessions. A findings briefing was given on the last day describing the weaknesses identified in each process area by specific practice. Practices in both Levels 2 and 3 were evaluated, but no level rating was given.

Following the appraisal, the EPG team members who had participated in the appraisal met with the flight software manager to discuss the weaknesses and her priorities for addressing them. Then the EPG determined what existing assets and resources could be applied in those areas and made an improvement proposal to the manager. Based on the improvement proposal and the flight software manager's priorities, five process action teams were formed to address weak areas.

5.3 The Second Appraisal (Systems Focus) The second appraisal was done from the project perspective, focusing on systems engineering and looking at the software components as acquisitions. Three major spacecraft projects

were chosen to participate. One was still in the formulation stages, nearing a systems requirements review. A second was a major project in mid-development, with about two years remaining until launch and the third was a project within a program developing a series of "turn-key" spacecraft. For this appraisal, the organization was considered to be GSFC, since GSFC is a matrix organization with personnel from different functional groups assigned to each of the projects.

Project participants were given an overview of CMMI, but not the three-day class. Although there was still a desire to minimize the amount of the project personnel time, participants were given lists of example types of documentation and sample types of questions.

Again, a team of six appraisers was used, with three SEI-certified Lead appraisers and three EPG members. This time, the EPG members included one systems engineer, one quality assurance person and one software person. The SEI-certified Lead appraiser asked the majority of the interview questions. The same methodology was followed as in the first appraisal, except that more emphasis was placed on interviews and less on documentation. The appraisal took five days, with most of three days devoted to interviews. The fourth day was used for document review and a draft findings meeting. The final briefing was presented in terms of weaknesses and strengths for the goals of the process areas in Levels 2 and 3.

6.0 Lessons Learned to Date To date, initial evaluations of the activities and the processes used during Phase 1 are being summarized and have resulted in lessons learned for future activities. Some lessons learned are GSFC-specific, but many others may be useful to other organizations beginning process improvement. The ones presented here relate to training, choice of organization for improvement, management support, and mini-appraisal lessons.

6.1 Definition of the "organization" can be difficult For the first appraisal, GSFC defined the "organization" to be appraised as the line organization that contained developers/engineers producing like types of component software or services. Examples of these types of organizations would be "flight software organization", "ground software organization", or "systems engineering organization".

Since GSFC uses a matrix organization, groups from each of these types of organizations are assigned to support each spacecraft project. The line management organization is responsible for the training and detailed process activities of these groups, but all project management activities (requirements, schedules, budgets, interface coordination, etc.) are performed by the spacecraft project organization. For the second appraisal, the “organization” was defined as GSFC, a much larger entity, which contains both the spacecraft project organizations as well as the smaller component organizations.

The advantage of defining the organization using the component types of organizations is that the scope you are dealing with is much smaller. The primary disadvantage in a matrixed organization such as GSFC is that many of the process areas are addressed at GSFC by other component organizations, making it very difficult to determine whether the appropriate practices are being performed without looking in detail at the other supporting organizations.

6.2 Management support is key to finding co-operative pilots Typical projects at GSFC have deadline-driven schedules and a budget that is usually less than desirable. Thus project managers are not anxious to engage in any types of activities such as appraisals or classes that will not directly assist them with their primary goal—that of delivering an operational spacecraft system. Initially, the EPG members spoke with many of the project managers about participating in the Phase 1 pilot areas. Very few were willing to participate in the appraisals.

In order to obtain participants for the second set of appraisals, the EPG enlisted assistance from the MOG. One of the members of the MOG accompanied the EPG member to present the request for participation to senior management in both Engineering and Flight Projects and then to the projects themselves. Using this approach, every project contacted agreed to participate.

6.3 Mini-appraisals by an outside group provide a good starting point Many organizations beginning process improvement start by working on the areas they feel are weak, without having any outside input on where their actual weak areas are. GSFC chose to have SEI-certified appraisers outside NASA help them with their initial benchmarking against the CMMI model.

In retrospect, there are many advantages to this approach.

First, in one short week, we were able to amass a tremendous amount of information on exactly how activities were being performed in different areas and what documentation was being used. By using multiple projects in our “pilot areas”, we also got a good view of the consistency of activities across projects.

The use of appraisers outside NASA enabled the EPG to get a good view of exactly how the existing GSFC processes and documentation would be viewed in a more formal appraisal. In some cases, the documentation reviewed was considered sufficient by the outside appraisers, when the EPG would have considered that additional documentation was necessary. The use of outside appraisers also gave a more official flavor to the mini-appraisals, which encouraged the participating projects to assure that the appropriate people would be available for interviews.

Finally, the major benefit of using the mini-appraisals with certified Lead appraisers was the training it provided to the EPG members participating in the appraisals. EPG members now have a very clear idea of exactly how a SCAMPI appraisal would be conducted, and a very good idea of how the CMMI model would be applied to activities at GSFC. In addition, the process of going through an appraisal is very helpful in becoming more familiar with the CMMI model and its interpretation. The model is very large and complicated, and it takes time to learn it well. The appraisal process provides a practical way to increase model knowledge in a short time period.

6.4 Mini-Appraisal Lessons Learned In comparing the process used for performing the two mini-appraisals, we were able to draw the following conclusions:

- Allow enough preparation time: It takes time to schedule interviews, handle logistics and plan for an appraisal. We spent at least several weeks in preparation.
- Preparation of participants yields better results. During the second appraisal, when we helped participants identify documentation and provided sample types of questions, we were able to get more accurate results. In the first appraisal, some participants neglected to mention some

critical activities that were being performed since they were not very familiar with the CMMI model.

- The CMMI model worked well to evaluate system engineering activities. The focus of the second appraisal was systems engineering with a large amount of time devoted to baselining system engineering activities. Both the GSFC personnel and an outside systems engineering expert felt that the CMMI model provided a reasonable measurement tool for benchmarking these activities.
- Do a draft findings briefing. A draft findings briefing helps identify any misunderstandings or gaps in information that might exist after the interview periods.
- Follow-up is important. When projects have agreed to participate in appraisals and process improvement activities, they need to receive the feedback from the appraisal in a timely fashion, as well as information on follow-on activities.

6.5 Provide the right training for the right people

One group of project participants was given a three-day CMMI class and the other group was given a CMMI overview. We recommend the overview training for project participants. The knowledge the project participants really needed was a good knowledge of the processes used on their projects and the higher levels of process documentation from which their project documentation was derived. The three-day CMMI class was a significant time commitment for most of the project people and they felt overwhelmed with the volume of information. Many attendees thought all process area practices needed to be satisfied by their local organization and overlooked the contributions of the supporting organizations.

All EPG members received the three-day CMMI training. The detailed knowledge of CMMI has provided many benefits to the EPG team, allowing them to assist in mapping existing practices to those of CMMI and to identify alternative practices that are being used.

7.0 Metrics In order to determine the effectiveness of the software/systems development process improvement effort, metrics will be collected. The initial metrics that will be collected will be used to determine implementation progress, cost and effort. As the process improvement effort continues,

information will be collected that will facilitate assessment of CMMI benefits in the areas of error reduction, cost estimation, productivity and schedule deviations. The cost impact of these benefits will be compared to the cost of implementation to compute a return on investment (ROI).

Conclusion As GSFC completes its first year of process improvement and the end of Phase 1 activities, we are finding that the CMMI model is a useful way to measure an initial capability state of an organization and to identify improvement opportunities. The initial activities of the year have assisted us in establishing a good workable infrastructure for improvement, training our process improvement team members, baselining our current capabilities, and gaining a better understanding of the cost and effort necessary to continue our process improvement efforts. All of this information, as well as our lessons learned during the past year will facilitate our planning for a successful transition into Phase 2....the phased inclusion of many more projects.